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# Argonne National Laboratory

## PHYSICS DIVISION SUMMARY REPORT

September—December 1966

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Physics
AEC Research and
Development Repor


ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439


# PHYSICS DIVISION SUMMARY REPORT

September—December 1966


Lowell M. Bollinger, Division Director



Preceding Summary Reports:

ANL-7218, May 1966
ANL-7246, Annual Review
ANL-7247, June-August 1966

# FOREWORD

The Physics Summary is issued several times per year for the information of the members of the Division and a limited number of other persons interested in the progress of the work. It includes short reports on highlights of the current research, abstracts or short summaries of oral presentations at meetings, abstracts of papers recently accepted for publication, and publication notices of papers appearing in recent journals and books. Many of these reports cover work still in progress; the results and data they present are therefore preliminary, tentative, and often incomplete.

The research presented in any one issue of the Summary is only a small random sample of the work of the Physics Division. For a comprehensive overview, the reader is referred to the ANL Physics Division Annual Review issued each summer, the most recent being Argonne National Laboratory Report ANL-7246 which reports research in the year ending 31 March 1966.

The issuance of these reports is not intended to constitute publication in any sense of the word. Final results will be submitted for publication in regular professional journals or, in special cases, presented in ANL Topical Reports.

# FOREWORD

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# I. RESEARCH HIGHLIGHTS

These research highlights are Physics Division contributions to the Physical Research Monthly Report which the Laboratory Director's Office sends to the Division of Research of the U. S. Atomic Energy Commission. They report interesting work that is currently in progress or that has just been completed.

## PARTIAL RADIATIVE WIDTHS IN NEUTRON CAPTURE, AND FINAL-STATE STRUCTURE

W. V. Prestwich and R. E. Coté

An investigation of the reduced widths for neutron transitions in deuteron stripping reactions leads to invaluable information regarding the structure of nuclear eigenstates. An analogous reaction that may lead to population of the same states is neutron capture. With the recent development of lithium-drifted solid-state detectors, the spectrum of electromagnetic radiation following the capture of an incident neutron can now be studied with sufficiently high resolution to make a detailed comparison between the two reactions.

The capture-gamma-ray experiment required for a comparison between the (n, γ) and (d, p) reactions consisted of a measurement of the gamma-ray spectra associated with neutron capture by $Co^{59}$ and $Mn^{55}$ targets, at incident energies corresponding to known resonance states of the compound nuclei. The targets were exposed to the pulsed neutron beam of the Argonne fast-chopper facility at the CP-5 reactor. For each event, the incident neutron energy and resultant gamma-ray energy were recorded on magnetic tape in the form of the time of flight and the pulse height, respectively. A lithium-drifted germanium device with an active volume of 6 cc was used to detect the gamma rays.

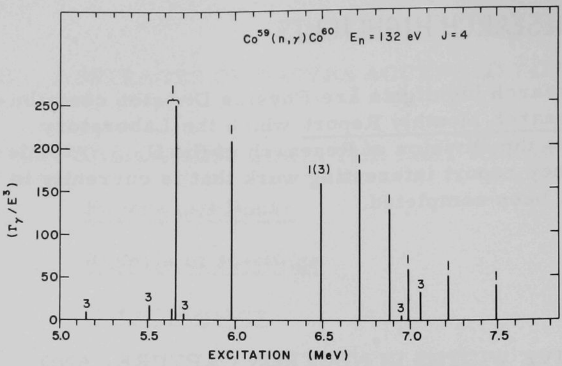


Fig. 1. The correlation between the reduced widths $\Gamma_\gamma/E^3$ and the values of $\ell_n$ for the final states in $Co^{60}$.

Figure 1 is a plot of the reduced radiative widths observed in the spectrum from capture in the 130-eV resonance of $Co^{59}$. For each transition, the value of the major orbital-angular-momentum component in the corresponding deuteron stripping transition is indicated. The data indicate a general trend in which the reduced widths for transitions leading to final states for which $\ell_n = 1$ are larger than those for final states with $\ell_n = 3$. Averaging the data gives the ratio

$$\frac{\langle \Gamma_\gamma / E^3 \rangle_{\ell_n = 3}}{\langle \Gamma_\gamma / E^3 \rangle_{\ell_n = 1}} = 0.12 \pm 0.08.$$

This result is consistent with the suggestion that the initial radiating state may be represented as an s-wave nucleon coupled to the target nucleus. This model is appropriate for the region of the reaction phase space from which direct-capture contributions may occur. The selection rule for electric-dipole radiation between pure shell-model states requires $\Delta\ell = 1$. Since for the above model $\ell = 0$ initially, this rule implies that $\ell = 1$ states are the only ones populated; hence transitions to final states for which $\ell = 3$ are forbidden. The fact that the $\ell = 3$ transitions are much weaker than the $\ell = 1$ transitions seems to indicate that the model is approximately valid, but not rigorously so.

The reduced neutron widths observed in deuteron stripping for $\ell_n = 1$ represent the fraction of the single-particle 3p strength contained in the given final state. The partial radiative width is related to the matrix element $\langle f|E1|i\rangle^2$ for electric-dipole radiation between initial and final states $|i\rangle$ and $|f\rangle$, respectively. If the initial state is described by an s-wave neutron coupled to the target, then from the general property $E1|s\rangle = |p\rangle$ it follows that the radiative widths are related to $(f/p)^2$. This is just the reduced neutron width in the deuteron stripping reaction. Therefore, the existence of a correlation between the strengths of radiative widths and (d, p) neutron widths is to be expected for this model. The data for $Co^{59}(n,\gamma)Co^{60}$ and $Co^{59}(d,p)Co^{60}$ do not exhibit the expected correlation to a significant extent.

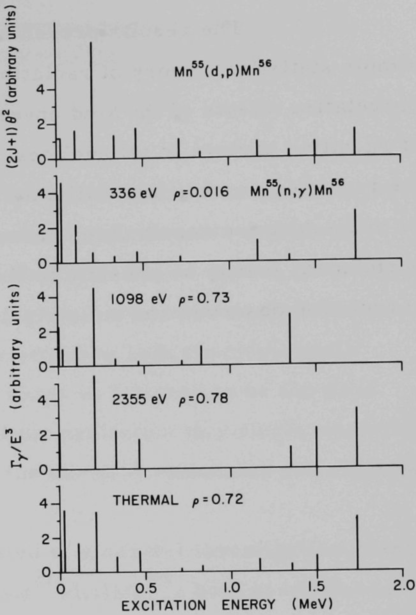


Fig. 2. Comparison between the reduced widths for the $\ell_n$=1 transitions in manganese and the reduced neutron (d, p) widths.

The results of a similar comparison between the reactions $Mn^{55}(n,\gamma)Mn^{56}$ and $Mn^{55}(d,p)Mn^{56}$ are given in Fig. 2, where the deuteron stripping widths are compared with the corresponding radiative widths observed in the gamma spectra for four neutron energies. With the correlation coefficient $\rho$ defined so that $\rho = 0$ for uncorrelated variables and $\rho = 1$ for complete correlation, it can be seen from the magnitudes of $\rho$ given in the figure that three of the four $(n,\gamma)$ spectra appear to exhibit a correlation with the (d, p) spectra.

The results presented above suggest strongly that the simple statistical theory of radiation widths, which cannot account for correlation effects of the kind observed, is not an adequate description of radiative capture in all nuclides. However, the factors that control the radiative process are still only vaguely understood. It is hoped that as more data are accumulated and more refined experiments are performed, it may be possible to find a relation between the degree of correlation observed and an intrinsic property of the resonance involved.

# EVIDENCE FOR MULTIPLE-EXCITATION EFFECTS IN A SINGLE-PARTICLE-TRANSFER REACTION

D. Dehnhard and J. L. Yntema

One of the most fruitful concepts in the interpretation of nuclear reactions has been the idea that nucleon-transfer reactions proceed by a simple direct process. Recently, however, the possibility that a multiple-excitation process may play a role in weak transitions of this kind has received considerable attention both experimentally and theoretically. The present experiment is believed to be the first one that shows the occurrence of multiple excitation in a single-nucleon-transfer reaction clearly and without the use of questionable assumptions about the structure of the nucleus.

The experiment consisted of a careful investigation of the two reactions $Mg^{26}(He^3,\alpha)Mg^{25}$ and $Mg^{26}(d,t)Mg^{25}$, both of which are neutron-pickup reactions. The measurements were performed with the 33-MeV $He^3$ beam and the 21.6-MeV deuteron beam of the Argonne 60-in. cyclotron. The particles were detected with a telescope of surface-barrier detectors. The experimental resolution width varied between 100 and 15 keV.

A typical α-particle spectrum is shown in Fig. 3. The $\frac{7}{2}^+$ level of $Mg^{25}$ at 1.61 MeV is well resolved from known neighboring levels. However, the $\frac{9}{2}^+$ level at 3.399 MeV could not be resolved from the $\frac{3}{2}^-$ level at 3.408 MeV. The spectrum clearly shows that the $\frac{7}{2}^+$ level is more strongly excited than the combination of the $\frac{9}{2}^+$ and $\frac{3}{2}^-$ levels.

For both the $(He^3,\alpha)$ and (d,t) reactions, Fig. 4 shows the angular distributions of the transitions to the ground state, the 1.611-MeV state, and the unresolved doublet at 3.4 MeV, together with calculated curves. In the $(He^3,\alpha)$ reaction, the distributions for the

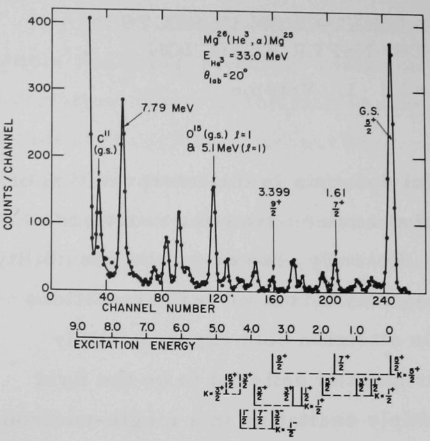


Fig. 3. Spectrum of α-particle energies.

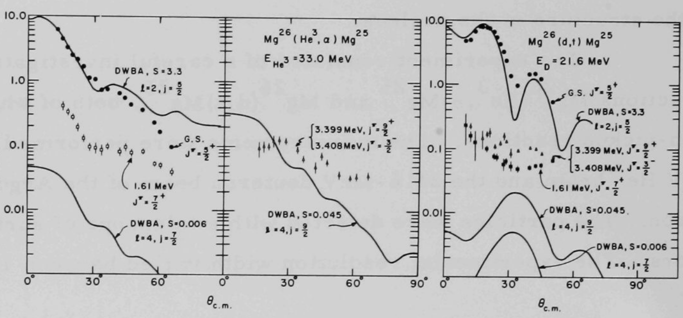


Fig. 4. Experimental and calculated differential cross sections.

transitions to the $J^{\pi}=\frac{7}{2}^{+}$ state and the unresolved doublet at 3.4 MeV have markedly different shapes. Since the transition to the $\frac{9}{2}^{+}$ state in the doublet is much stronger than that to the $\frac{3}{2}^{-}$ state, this means that the distributions of the transitions to the $\frac{7}{2}^{+}$ and $\frac{9}{2}^{+}$ states have very different shapes, even though the orbital-angular-momentum transfer in both transitions is $\ell = 4$. This difference in shape is convincing evidence that both transitions cannot proceed by simple direct processes; if they did, the distributions would be closely the same at forward angles.

Other characteristics of the measured spectra support this conclusion. One piece of evidence is the observation that the transition to the $\frac{7}{2}^+$ state is stronger than that to the $\frac{9}{2}^+$ state, whereas both qualitative shell-model considerations and detailed calculations with Nilsson-model wave functions show that the transition to the $\frac{9}{2}^+$ state should be the stronger of the two by an order of magnitude. In addition, the absolute value of the $\frac{7}{2}^+$ cross section is an order of magnitude larger than would be expected from theoretical considerations.

In view of the differences in the shapes of the two $\ell=4$ distributions and the anomalies in the relative and absolute values of the strengths of the transitions, it seems clear that the excitation of the $\frac{7}{2}^+$ state cannot be due to a reaction involving direct single-nucleon transfer only; hence some more complex mode of excitation must be involved. This conclusion about the reaction mechanism of a particular transition is interesting in itself and it also suggests that considerable restraint should be used in a direct-reaction interpretation of all weak pickup reactions.

## STUDIES OF THE STRUCTURE OF EARLY 1d2s-SHELL NUCLEI

A. Arima, S. Cohen, R. D. Lawson, and M. H. Macfarlane

Nuclear theorists have tried for many years to understand the experimental properties of the "sd shell" nuclei, using various approximations in addition to the fundamental assumptions of the nuclear shell model. These studies were invariably clouded by the unknown effects of approximations imposed purely by the mathematical complexity of the problem. In addition, the comparison with experimental data was hampered by insufficient understanding of which nuclear states should be regarded as shell-model states and which ones involve more complicated excitations.

In a recent study, making use of the Argonne automated shell-model program, it has finally become possible to remove both of these barriers to progress in the sd shell. The shell model in which only the $1d_{5/2}$ and $2s_{1/2}$ single-particle levels are taken into account and in which the residual two-body interaction is characterized in terms of its matrix elements was used successfully to predict not only the experimentally observed spectra of $O^{18,19,20}$, $F^{18,19,20}$, and $Ne^{20}$ but also the observed transition rates and static multipole moments of these nuclei. Some of the transition rates predicted on the basis of this model have recently been confirmed by a Doppler-shift measurement at Argonne. These measurements should be followed by further experimental checks on the energies and other properties predicted for the excited nuclear states—particularly for the second or third states of each spin. This would be a very useful indication of how well the effects of core excitation can be taken into account by a model in which the effective interaction is characterized in terms of its matrix elements and an effective charge is used to describe the gamma decay of the states.

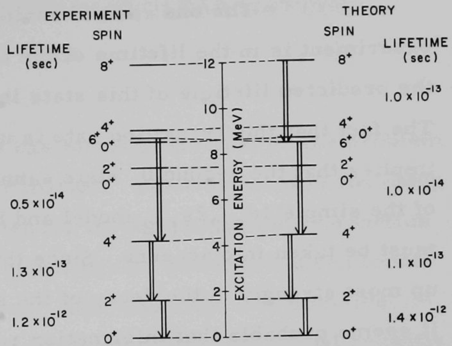


Fig. 5. Comparison of theoretical predictions and experimental results for $Ne^{20}$. The theoretical spectrum is the result when the sixteen two-body matrix elements that characterize the residual interaction within the $1d_{5/2}2s_{1/2}$ configuration is least-squares fitted to the 36 known energy levels in oxygen, fluorine, and neon. The rms error in the fit to any one of these 36 energies is 225 keV. The additional positive-parity states observed above 7 MeV in neon (not shown in the figure) are interpreted as resulting from either core excitation or excitation of one or more of the valence nucleons to the $1d_{3/2}$ single-particle level. The E2 lifetimes for gamma-ray transitions between some members of the ground-state rotational band have been measured and are shown in the figure. The shell-model predictions for these transitions (also shown) agree well with experiment.

If the eight protons and eight neutrons of $O^{16}$ are assumed to form an inert core and if the neutrons outside the core are allowed to populate only the $1d_{5/2}$ and $2s_{1/2}$ single-particle states, then the spectra of the early 1d2s-shell nuclei can be characterized in terms of sixteen matrix elements that describe the residual two-body interaction. The spectrum of $Ne^{20}$ (Fig. 5) illustrates how successfully the data are explained by a least-squares fit of these 16 parameters to the 36 states of known spin and parity in $O^{18,19,20}$, $F^{18,19,20}$, and $Ne^{20}$.

The wave functions that characterize these levels can be used to predict various transition rates. If the neutron and proton are endowed with effective charges of 0.7 and 1.7, respectively, all but one of the observed E2 transition rates are predicted within a factor of two of their experimental values. Some of these results are shown in Fig. 5. In addition, the M1 lifetime of the J=0 T=1 state in $F^{18}$ is predicted to be $0.5 \times 10^{-14}$ sec in good agreement with the $\tau = 0.4^{+0.3}_{-0.2} \times 10^{-14}$ sec from the Argonne Doppler-shift measurement.

The one case of serious disagreement between theory and experiment is in the lifetime of the excited $0^+$ state at 3.63 MeV in $O^{18}$; the predicted lifetime of this state is fifty times the experimental value. The fact that this transition rate is underestimated by such a large factor implies that the second $0^+$ state cannot be adequately described in terms of the simple $1d_{5/2}2s_{1/2}$ model and hence excitation of the $O^{16}$ core must be taken into account. Since this core excitation seems to show up most strongly in the decay of the second state of spin zero in $O^{18}$, it seems probable that information relating to the lifetime of the second or third nuclear state of given spin will give valuable information on the existence of core excitation in the early 1d2s-shell nuclei.

# THREE-BODY CORRELATIONS IN NUCLEAR MATTER

B. D. Day

Recent work by Bethe has focused attention on the problem of three-body correlations in nuclear matter. The treatment of two-body correlations is well understood and leads, through Brueckner's reaction matrix, to the replacement of the highly singular nucleon-nucleon force by a well-behaved effective interaction. One then uses this effective two-body interaction to calculate three-body correlations. Until recently such calculations were always done by perturbation theory, but Bethe's paper of 1965 showed conclusively that the perturbation series diverges badly and leads to completely wrong results. Instead of a relatively simple perturbation calculation, a correct treatment requires a complete solution of the three-body Bethe-Faddeev equations, which describe the simultaneous interaction of three particles inside the nucleus.

In his original paper, Bethe obtained an analytic approximation for the three-body wave function. The new approximate analytic solution developed in the present work has several advantages over the old one. The new solution is more accurate and is a continuous function; in contrast, the old solution has a number of unphysical discontinuities. The new solution also turns out to be much superior as a starting point for detailed numerical calculations.

The old solution is a quotient of two functions, each of which is a polynomial in the two-body correlation functions. The fact that the two polynomials may vanish simultaneously is responsible for the discontinuities in the old solution. The new solution is a single polynomial of two-body functions and is necessarily continuous because the two-body functions are continuous. These points are illustrated in Fig. 6, in which the old and new approximations for the three-body function $Z^{(1)}(r_{12}, r_{13}, r_{23})$ are plotted against $r_{23}$. The unit of distance is the radius c of the hard

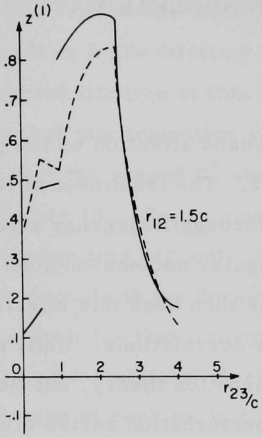


Fig. 6. The three-body function $Z^{(1)}(r_{12}, r_{13}, r_{23})$ plotted against $r_{23}$, with $r_{12} = 1.5$ c, $r_{13} = |1.5\text{ c} - r_{23}|$. The old and new approximate solutions are represented by the solid and dashed lines, respectively. (Taken from the Ph. D. thesis of M. W. Kirson, Cornell University, 1966.)

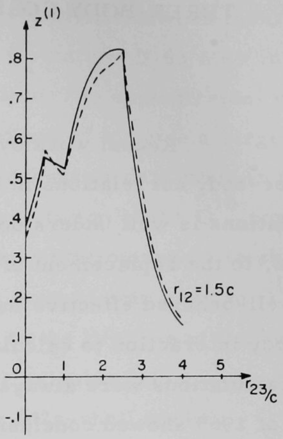


Fig. 7. The new analytic approximation (solid curve) and a first iteration (dashed curve) for $Z^{(1)}(r_{12}, r_{13}, r_{23})$ as a function of $r_{23}$, with $r_{12} = 1.5$ c, $r_{13} = |1.5\text{ c} - r_{23}|$. (Taken from the Ph. D. thesis of M. W. Kirson, Cornell University, 1966.)

core in the nucleon-nucleon interaction, and $r_{12}$ and $r_{13}$ are chosen equal to 1.5 c and $|1.5\text{ c} - r_{23}|$, respectively. The old solution (solid line) exhibits two rather large discontinuities, while the improved approximation (dashed line) is continuous.

The utility of the new solution in numerical work has been demonstrated by extensive computer calculations carried out by M. W. Kirson at Cornell. He uses the new analytic solution as the first approximation in an iterative procedure. The second approximation, which is generated by the computer, is then found to agree very well with the first approximation. A typical result is shown in Fig. 7, where the values of $(r_{12}, r_{13}, r_{23})$ are the same as in Fig. 6. The solid line is the new analytic approximation, and the dashed line represents a first iteration of the solid line. The agreement between the two curves is so good that acceptable numerical results can be obtained by using the analytic approximation as it stands, without further improvement.

Thus the new approximate analytic solution appears to be an extremely useful tool for the investigation of three-body correlations in nuclear matter. The solution should also be applicable to other many-body systems, such as liquid $He^3$, in which the two-body force contains a strong repulsion at short distances.

# II. REPORTS AT MEETINGS

The abstracts and summaries that follow are not necessarily identical to those submitted for the meeting. In some cases, the authors have corrected or expanded abstracts; and summaries of contributed papers commonly have been shortened.

## Topical Conference on Physics of Free Atoms
## Berkeley, California, 12—14 September 1966

### HYPERFINE STRUCTURE OF $V^{51}$ IN MANY LEVELS; COMPARISON OF THEORY AND EXPERIMENT, AND THE GROUND-STATE NUCLEAR ELECTRIC-QUADRUPOLE MOMENT

W. J. Childs and L. S. Goodman

The magnetic-dipole and electric-quadrupole hyperfine-interaction constants $A_J$ and $B_J$, and the electronic g factors $g_J$ have been measured for the nine (atomic) states of the two lowest terms ($3d^3 4s^2\ {}^4F$ and $3d^4 4s\ {}^6D$) of $V^{51}$ by the atomic-beam magnetic-resonance technique. The large body of data obtained provides a sensitive test of the theory of the hyperfine interaction.

Intermediate-coupling wave functions for each of the nine levels were constructed by a computer program which varied the appropriate Slater and spin-orbit parameters to make least-square fits to the optical term energies in the configurations of interest. With these wave functions, the quantities $A_J$ and $B_J$ were then predicted theoretically. The Hamiltonian for the magnetic-dipole hfs used parameters appropriate for including the effects of configuration interaction and relativity, while that for the electric-quadrupole hfs included configuration interaction but neglected the very small contributions of relativity.

The observed values of $A_J$ and $B_J$ were corrected for admixture of states of different J (since the spin-orbit interaction, considered explicitly above, mixes only states of the same J). These admixtures, caused by off-diagonal matrix elements of the various hyperfine operators, were substantial and resulted in corrections of up to 17% in the observed values of the nuclear ground-state electric-quadrupole moment.

Comparison of the theoretical and experimental values of the hyperfine interaction constants shows remarkably good agreement. For the magnetic-dipole constants, agreement is to within 0.007% for one multiplet, and 0.13% for the other. For the quadrupole interaction, which is more complex theoretically, agreement is within 3%. The differences are understood only in part. The comparison is summarized in Table I.

The electric-quadrupole moment of the nuclear ground state is found to be $Q(V^{51}) = -0.052 \pm 0.010$ b from both configurations. This value is, in contrast to the previously measured value, in relatively good agreement with theoretical predictions. That the values obtained for Q from the two electronic configurations are the same to within 3% shows that the Sternheimer effect is very nearly the same for the two cases, although its exact magnitude in either configuration is still unknown.

In evaluating the electronic g factors from the data, the corrections for J mixing were complicated by the presence of the Zeeman operator which acts as an additional mixing agent. Large shifts in the observed resonance frequencies were found to be due primarily to interference terms between the Zeeman and the magnetic-dipole hyperfine operators. Consistency between theory and experiment was found when these effects were properly taken into account.

TABLE I. Best fits to the corrected experimental values of $A_J$ and $B_J$ in $V^{51}$.

| Configuration | State | A factor Calc. (Mc/sec) | A factor Obs. (Mc/sec) | A factor Diff. (%) | B factor Calc. (Mc/sec) | B factor Obs. (Mc/sec) | B factor Diff. (%) |
|---|---|---|---|---|---|---|---|
| $3d^3 4s^2$ | $^4F_{9/2}$ | 227.133 | 227.136 | -0.001 | 8.339 | 8.259 | -1.0 |
| | $^4F_{7/2}$ | 249.769 | 249.752 | 0.007 | 5.560 | 5.595 | 0.6 |
| | $^4F_{5/2}$ | 321.233 | 321.251 | -0.006 | 3.932 | 3.964 | 0.8 |
| | $^4F_{3/2}$ | 560.073 | 560.069 | -0.001 | 4.003 | 3.982 | -0.5 |
| $3d^4(^5D)4s$ | $^6D_{9/2}$ | 407.168 | 406.852 | -0.08 | 14.166 | 14.344 | 1.2 |
| | $^6D_{7/2}$ | 381.879 | 382.369 | 0.13 | 2.361 | 2.442 | 3.3 |
| | $^6D_{5/2}$ | 373.326 | 373.529 | 0.05 | -5.059 | -4.942 | 2.4 |
| | $^6D_{3/2}$ | 406.078 | 405.648 | -0.11 | -7.083 | -6.916 | 2.4 |
| | $^6D_{1/2}$ | 751.491 | 751.545 | 0.01 | 0 | 0 | 0 |

International Conference on Nuclear Physics

Gatlinburg, Tennessee, 12—17 September 1966

## AN INVESTIGATION OF NEUTRON PICKUP FROM $B^{11}$

D. Dehnhard,* G. C. Morrison, and Z. Vager†

The intermediate-coupling model has been very successful in its description of nuclei in the 1p shell, in particular in its prediction of γ-ray transition probabilities.[1—3] Further tests of the validity of this model are the comparison of theoretically predicted spectroscopic factors with values extracted from single-nucleon-transfer reactions. Although there are uncertainties in the applicability of the DWBA theory (as presently formulated) to direct reactions on very light nuclei, comparison of reactions such as (p,d) and (d,t) on the same target could give an estimate of these uncertainties since both reactions should yield the same spectroscopic factors if they proceed by single-neutron pickup.

We have studied the $B^{11}(d,t)B^{10}$ reaction at an incident-deuteron energy of 21.6 MeV at the Argonne 60-in. cyclotron with a $\Delta E \times E$ counter telescope for particle identification. Figure 8 shows the measured differential cross sections at forward angles between $\theta_{lab} = 6^{o}$ and $60^{o}$. The 5.16-MeV state ($J^{\pi} = 2^{+}$, T = 1) was not resolved from the 5.11-MeV state ($J^{\pi} = 2^{-}$, T = 0); but the latter state, which can only be reached by the pickup of a $2s_{1/2}$ particle, is expected to

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[1] D. Kurath, in Alpha-, Beta-, and Gamma-Ray Spectroscopy, edited by K. Siegbahn (North-Holland Publishing Co., Amsterdam, 1965), pp. 583-596.

[2] S. Cohen and D. Kurath, Nucl. Phys. 73, 1 (1965).

[3] D. Kurath (private communication).

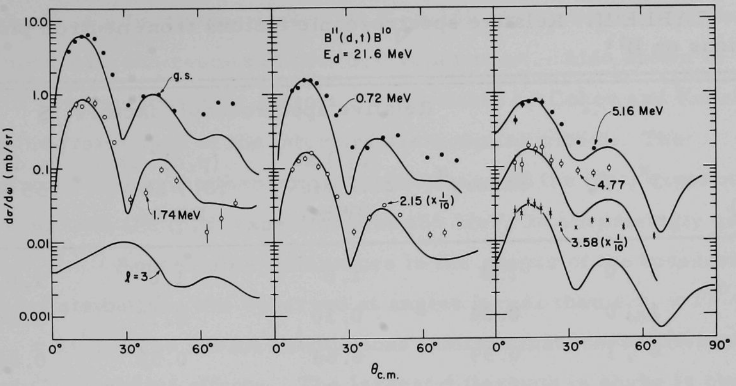


Fig. 8. Angular distributions of the $B^{11}(d,t)$ reaction and DWBA calculations. The parameters of the optical-model potential of Woods-Saxon shape are:

$B^{11}$ + d: V = 83.5 MeV, W = 14.94 MeV, $r = r_c = 1.33$ fm, a = 0.65 fm [Ref. 6].

$B^{11}$ + t: V = 160.5 MeV, W = 17.6 MeV, $r = r_c = 1.4$ fm, a = 0.626 fm [R. N. Glover and A. D. W. Jones, Phys. Letters 16, 69 (1965)].

The $\ell$=3 angular distribution is multiplied by $10^{-2}$ relative to the ground-state $\ell$=1 angular distribution.

be only weakly excited. The absolute cross section has an uncertainty of approximately 20%.

DWBA calculations (Fig. 8, solid lines) have been performed with the aid of the Oak Ridge code TSALLY[4] and extracted spectroscopic factors normalized to the $B^{10}$ ground state are shown in Table II. Also shown are relative spectroscopic factors which have been extracted from a DWBA analysis of previously published results[5] on the $B^{11}(p,d)$ reaction at 18.9 MeV by use of parameters listed by Winner

[4] R. H. Bassel, R. M. Drisko, and G. R. Satchler, Oak Ridge National Laboratory Report ORNL-3240.

[5] J. C. Legg, Phys. Rev. 129, 272 (1963).

TABLE II. Relative spectroscopic factors from neutron pickup reactions on $B^{11}$.

| $E_x$ (MeV) | $J^\pi$, T | Theory[a] | (d,t) at 21.6 MeV, DWBA | $(p,d)^b$ at 18.9 MeV, DWBA | $(p,d)^c$ at 155 MeV |
|---|---|---|---|---|---|
| | | Relative spectroscopic factors, S | | | |
| 0.0 | $3^+$, 0 | 1.0 | 1.0 | 1.0 | 1.0 |
| 0.717 | $1^+$, 0 | 0.24 | 0.30 | 0.17 | 0.24 |
| 1.74 | $0^+$, 1 | 0.59 | 0.64 | 0.50 | 0.53 |
| 2.15 | $1^+$, 0 | 0.49 | 0.41 | 0.19 | 0.52 |
| 3.58 | $2^+$, 0 | 0.24 | 0.15 | 0.09 | 0.12 |
| 4.77 | $3^+$, 0 | 0.13 | 0.12 | . . . | . . . |
| 5.11 | $2^+$, 1 | 1.56 | 1.91 | . . . | 2.67 |

[a] Calculations based on the (8—16) potential of Ref. 2.

[b] Reference 5.

[c] Reference 7.

and Drisko.[6] For the two $J^\pi = 1^+$, T = 0 states, the relative factors for the (d,t) reaction are about twice those from the (p,d) reaction, whereas the transitions to the T=1 state at 1.74 MeV are in reasonable agreement. It may be that the (p,d) reaction at $E_p$ = 18.9 MeV is not treated properly by the DWBA theory in the local, zero-range approximation with spin-orbit effects neglected. That the observed discrepancies may be due to this inadequacy is suggested from the results (Table II)

[6] D. R. Winner and R. M. Drisko, Technical Report, Department of Physics and Sarah Mellon Scaife Radiation Laboratory, 1965.

of analysis of a (p, d) experiment[7] at $E_p$ = 155 MeV, which show close agreement with the results of the (d, t) experiment. Also shown in Table II are spectroscopic factors as calculated by Cohen and Kurath[2,3] within the framework of the intermediate-coupling model. The agreement between the theoretical predictions and the (d, t) experiment, as well as with the (p, d) experiment at 155 MeV, is surprisingly good.

Appreciable differences in the shapes of the measured angular distributions are observed at angles larger than $\theta_{lab} = 17^\circ$ ($\theta_{c.m.} = 21^\circ$). The DWBA calculations indicate that these differences are not Q-dependent effects. The largest difference in shape is observed between the angular distribution of the ground-state ($J^\pi = 3^+$, T = 0) transition and the transition to the 1.74-MeV state ($J^\pi = 0^+$, T = 1), both of which are expected to proceed by the capture of a $j=\frac{3}{2}$ particle. However, an $\ell=3$ admixture in the ground state of $B^{11}$ cannot be completely excluded.[8] From the shape of the $\ell=3$ angular distribution shown in Fig. 8, it can be seen that the fit for the ground-state transition could be improved by assuming an $\ell=3$ contribution of the order of 20—30%.

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[7] D. Bachelier, M. Bernas, I. Brissaud, C. Detraz, and P. Radvanyi, Communication au Colloque sur les Noyaux Legres, Lyon, 1966.

[8] H. C. Meyer, W. T. Pinkston, and G. R. Satchler, Bull. Am. Phys. Soc. 8, 553 (1963).

## INTERMEDIATE STRUCTURE OBSERVED IN NEUTRON CROSS SECTIONS

A. J. Elwyn, J. E. Monahan, and F. P. Mooring

The cross sections and polarizations measured as a function of incident energy for neutrons scattered from $^{19}F$ show a resonance-like structure with widths that are larger than those usually associated with states of the compound nucleus but smaller than expected for single-particle resonances. From a phase-shift analysis of these data, we conclude that the observed "peaks" have many properties that are consistent with the interpretation of the structure in terms of doorway states. The amplitudes of similar structure observed in the total neutron cross sections of Mo and Sn can be explained in terms of expected statistical fluctuations of the widths and spacings of compound-nucleus levels, although the data appear to show correlations that are statistically inconsistent with this explanation.

## SPECTROSCOPIC FACTORS FOR FORBIDDEN TRANSITIONS

Dieter Kurath

Spectroscopic factors are calculated for transfer of 1f nucleons in some 1p-shell nuclei. The wave functions are determined by fitting observed E2 matrix elements. The particular example of pickup from $C^{12}$ contains a strong j dependence which is not observed in experiments. Therefore simple single-nucleon transfer does not seem to be an adequate mechanism.

## MEASUREMENTS OF MIXED $p_{1/2}$-$p_{3/2}$ (d,p) TRANSITIONS IN LIGHT NUCLEI

D. Kurath, G. C. Morrison, J. P. Schiffer, R. H. Siemssen, and B. Zeidman

The J dependence of the (d,p) angular distributions has been used to extract fractional-parentage coefficients for mixed $p_{1/2}$ and $p_{3/2}$ transitions in light nuclei. The agreement between measured and calculated mixing ratios is surprisingly good.

## SHELL-MODEL CALCULATIONS

R. D. Lawson and J. M. Soper*

The results that emerge from various characterizations of the residual two-body force will be discussed. First, one can parametrize the force in terms of its matrix elements. This approach leads to results in excellent agreement with experiment. On the other hand, although one can fit and predict spectra by assuming a pure configuration assignment there is no guarantee that large configuration impurities are absent. A second approach is to use the reaction matrix computed from the interaction between free nucleons. The computed matrix elements are quite similar to those deduced from the two-body matrix elements fitted to the data. However, small differences get magnified when the many-nucleon shell-model calculation is carried out. Thus the agreement between calculation and experiment is less dramatic in the many-nucleon case than in the two-particle nucleus. Alternatively, one can look for a force of simple form. To this end, the relative s-state interaction or the surface delta force leads to predictions in fairly good agreement with experiment. The success of these simple forces rests on the fact that they are specifically designed to take care of the dominant part of the residual force—the interaction in relative s states.

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*Work done while on leave from A. E. R. E., Harwell, Didcot, Berks., England.

## NUCLEAR PHYSICS CONCEPTS RELATED TO ELEMENTARY PARTICLE PHYSICS

H. J. Lipkin

This is a review of (1) the independent-quark model and the magic numbers, (2) some electromagnetic and weak interaction properties in the quark model, and (3) high-energy scattering in the quark model.

## THE GIANT DIPOLE RESONANCE IN SOME SELF-CONJUGATE NUCLEI IN THE 1s2d SHELL

L. Meyer-Schützmeister, R. E. Segel, and R. C. Bearse

In recent studies of the giant dipole resonance in a few light nuclei, it has become obvious that its features in such 1s1p-shell nuclei as $C^{12}$ and $O^{16}$ are markedly different from those in such 2s1d-shell nuclei as $Mg^{24}$ and $Si^{28}$. The distinctive characteristics of the resonance in $C^{12}$ and $O^{16}$ are that (1) the resonance decays by emitting neutrons and protons with equal intensities—as expected for self-conjugate nuclei, (2) the yields of the two particles are correlated, (3) the structure of the resonance is smooth and dominated by a few broad bumps. The results indicate that the giant dipole resonance consists mainly of one state in $C^{12}$ but of several in $O^{16}$. These states can be identified with particle-hole states, mostly in $(p^{-1}, d)$ configurations, which are calculated theoretically.

In contrast to this rather simple picture for 1s1p-shell nuclei, the giant dipole resonance of the 2s1d-shell nuclei (which has been most thoroughly investigated for the nuclei $Ne^{20}$, $Mg^{24}$, $Si^{28}$, and $S^{32}$)has a much more complicated structure. The results of the most recent study, an investigation of the $Na(p, \gamma_0)$ and $Na(p, \gamma_1)$ reactions leading through the giant dipole resonance to ground state and first

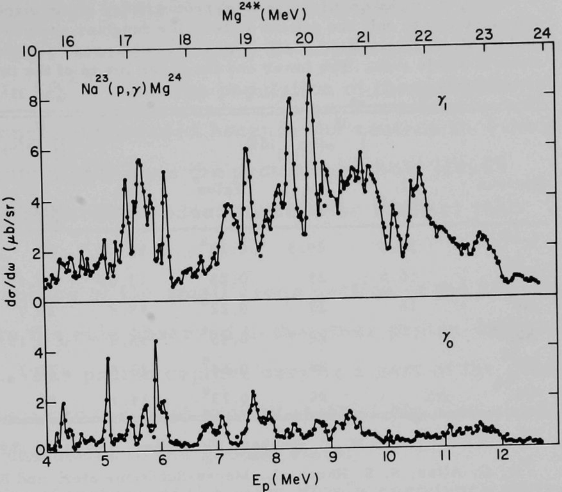


Fig. 9. $90^{\circ}$ yield for the $\gamma$ rays fitting the ground and first excited states of $Mg^{24}$. The yield curve was taken in 25-keV steps with a target of about this thickness to the proton beam.

excited state in $Mg^{24}$, are shown in Fig. 9. The differential cross sections, taken at 25-keV energy intervals, were measured with an Na target about 300 $\mu g/cm^2$ thick deposited on a C backing 10 $\mu g/cm^2$ thick. The curve is characterized by strong fluctuations or fine structure with widths of the order of 60—80 keV. Fine structure is also observed in $Si^{28}$ and $S^{32}$. This fine structure clearly indicates that in the s-d shell the strength of the giant dipole resonance is shared among many rather long-lived levels. A possible exception is $Ne^{20}$, for which the dipole resonance exhibits structure about 200 keV wide and no superimposed fine structure.

The cross sections $\sigma(\gamma, p_{all})$ for the total proton emission and $\sigma(\gamma, p_0)$ for the proton decay leading exclusively to the ground state of the daughter nucleus are listed in Table III for the giant dipole resonance region in a number of s-d shell nuclei and, for comparison, in $C^{12}$ and $O^{16}$. Each value is relative to the classical electric dipole sum. The branching ratio shows a striking trend for the fraction of proton decays to the ground state of the daughter nucleus to decrease as the weight of the nucleus increases. This must be connected with the

TABLE III. The total proton decay of the giant dipole resonance to all states combined and to only the ground state of the daughter nucleus are shown for a number of nuclei in the 1s1p shell and 2s1d shell. The integrated cross sections are given in units of the electric dipole sum. The lower and the upper limits of the integrations are listed as L and U, repsectively.

| Nucleus | $\int_L^U \sigma(\gamma p_{all})dE$ | | | $\int_L^U \sigma(\gamma p_0)dE$ | | | $\frac{\int \sigma(\gamma p_{all})dE}{\int \sigma(\gamma p_0)dE}$ |
|---|---|---|---|---|---|---|---|
| | L (MeV) | U (MeV) | Value | L (MeV) | U (MeV) | Value | |
| $C^{12}$ | 20.3 | 29.3 | 0.28[a] | 18 | 29 | 0.29[a,b] | 1 |
| $O^{16}$ | 16.6 | 27 | 0.23[a] | 13.08 | 25.15 | 0.12[a,c] | 2 |
| $Ne^{20}$ | 16 | 27 | 0.22[a] | 15.8 | 25.7 | 0.083[a,d] | 2.7 |
| $Mg^{24}$ | ... | 28 | 0.45[e] | 15.5 | 2.16 | ≤ 0.05[e—g] | ≈ 9 |
| $Si^{28}$ | ... | 28 | 0.64[e] | 15.4 | 23.2 | 0.14[e,h] | 4.5 |
| $Ca^{40}$ | ... | 28 | 0.73[e] | 14.1 | 23 | 0.13[e,i] | 5.6 |

[a]W. R. Dodge and W. C. Barber, Phys. Rev. 127, 1746 (1962).

[b]R. G. Allas, S. S. Hanna, L. Meyer-Schützmeister, and R. E. Segel, Nucl. Phys. 58, 122 (1964).

[c]E. D. Earle and N. W. Tanner (to be published).

[d]R. E. Segel, Z. Vager, L. Meyer-Schützmeister, P. P. Singh, and R. G. Allas, Nucl. Phys. (to be published).

[e]Sven A. E. Johannsen, Phys. Rev. 97, 1186 (1955).

[f]Measurements are in progress.

[g]B. Forkman and W. Shiefler, Nucl. Phys. 56, 615 (1964).

[h]P. P. Singh, R. E. Segel, L. Meyer-Schützmeister, S. S. Hanna, and R. G. Allas, Nucl. Phys. 65, 577 (1965).

[i]J. C. Hafele, F. W. Bingham, and J. S. Allen, Phys. Rev. 135, B365 (1964).

decreasing overlap between the nuclear configurations in the giant dipole resonance and those in the ground state of the daughter. In particular, the unusually small cross section for the proton decay to the ground state of $Mg^{24}$ (only about 0.1 of the total proton decay) can be understood from the fact that its ground state is well described by a nucleon configuration with seniority zero (i.e., with all nucleons paired). Absorption of an E1 photon would break up such a pair; and the resulting particle-hole state would decay strongly by emitting the excited particle. The daughter $Na^{23}$ would then be left in a hole state. But the spin-$\frac{3}{2}^+$ ground state of $Na^{23}$ is not such a hole state; so the proton decay of the giant dipole resonance goes mainly to the higher excited states instead.

Since $Mg^{23}$ is the mirror nucleus of $Na^{23}$, the neutron decay of the giant dipole resonance in $Mg^{24}$ would similarly be expected to go preferentially to excited states in $Mg^{23}$. But the population of these highly excited states will be strongly suppressed because the neutron threshold (16.55 MeV) is considerably higher than the proton threshold (11.69 MeV). The total neutron emission is indeed found to be smaller than the total proton emission.

One consequence of the small cross section of the $Mg^{24}(\gamma, p_0)$ reaction is an exception to the rule observed in the other proton-capture processes studied so far. The proton capture excites a part of the giant dipole in $Mg^{24}$, and its decay to the first excited state of $Mg^{24}$ is about three times as strong as the decay to the ground state.

Although the structure of the giant dipole resonance in the 2s1d-shell nuclei is very complex, the angular distributions from the $(p, \gamma_0)$ reactions on $Al^{27}$, $Ne^{20}$, and $Na^{23}$ vary only slightly with proton energy. In the latter case, which was studied over the range $4 \leqslant E_p \leqslant 10.3$ MeV, the gamma-ray distributions are nearly isotropic.

## FREQUENCY OF SPURIOUS "INTERMEDIATE RESONANCES" IN RANDOMLY GENERATED CROSS SECTIONS

P. P. Singh,* P. Hoffman-Pinther,* and D. W. Lang†

A program to generate cross sections with parameters chosen in a random fashion from preset distributions showed existence of spurious "intermediate structures." Calculations based on the model used and scanning of the cross section showed that in a sample of

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$25\ \Gamma_{c.n.}$ there is 30% chance of finding a resonance $6\ \Gamma_{c.n.}$ wide with $\sigma_{peak} = 1.4\ \sigma_{average}$. Widths alone, therefore, are not reliable signatures of the real intermediate structures.

Conference on Nuclear and Particle Physics

Glasgow, Scotland, 21—23 September 1966

## ENERGY LEVEL STRUCTURE OF ACTINIDE ELEMENTS AS OBSERVED AT HIGH RESOLUTION WITH (d, p) AND (d, t) REACTIONS

J. R. Erskine, A. M. Friedman,* and T. H. Braid

We are studying (d, p) and (d, t) reactions on even isotopes of Th, U, Pu, and Cm by use of 12-MeV deuterons and a broad-range magnetic spectrograph. Some of the (d, p) data have previously been reported.[1] The new (d, t) data greatly aid the interpretation. For example, the (d, p) reaction on $U^{234}$ and $U^{236}$ together with the (d, t) reaction on $U^{236}$ and $U^{238}$ give the positions and occupation numbers ($U^2$ and $V^2$) for the particle and hole states in $U^{235}$ and $U^{237}$. More than thirty levels up to $E_x \approx 1.6$ MeV in these isotopes were assigned to the following single-particle rotational bands: $[501]\frac{3}{2}^-$, $[501]\frac{1}{2}^-$, $[631]\frac{3}{2}^+$, $[631]\frac{1}{2}^+$, $[622]\frac{5}{2}^+$, $[624]\frac{7}{2}^+$, $[613]\frac{7}{2}^+$, $[620]\frac{1}{2}^+$, $[622]\frac{3}{2}^+$, and $[615]\frac{9}{2}^+$. The values of $U^2$ for these levels agree rather well with a BCS pairing calculation. However, we are unable to assign a group of levels at 800—1100 keV excitation to bands based on single-particle states. In addition, the values of $U^2$ for these levels differ widely from the values predicted by the calculation. We therefore believe that these are collective levels.

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*Chemistry Division.

[1] T. H. Braid, R. R. Chasman, J. R. Erskine, and A. M. Friedman, Phys. Letters 18, 149 (1965).

## International Conference on Electron Nuclear Hyperfine Interactions in Spectroscopy

## New Zealand, 17—21 October 1966

### THE MÖSSBAUER EFFECT IN METALLIC CESIUM

Gilbert J. Perlow and A. J. F. Boyle*

The isotope $Cs^{133}$ of 100% relative abundance, has an 81-keV transition suitable for observation of the Mössbauer effect. The nuclear ground state has spin-parity $\frac{7}{2}^+$ while the excited state has $\frac{5}{2}^+$. The transition is predominantly M1 with an E2/M1 ratio of about 2%. The internal-conversion coefficient is $\alpha = 1.66$ and the half-life of the excited state is $6.3 \times 10^{-9}$ sec. The observable minimum line width is then $2\Gamma_n = 0.54$ mm/sec. The cross section at resonance is $\sigma_0 = 1.07 \times 10^{-19}\ \mathrm{cm}^2$ and the recoil energy expressed as a temperature is $E_r = 307^\circ$K. The excited state is obtained in high yield from the decay of 7.2-year $Ba^{133}$.

The preferred source for the Mössbauer effect in cesium, according to our earlier work,[1] is an alloy of barium in aluminum, of composition $BaAl_n$ with $n \geqslant 4$. The recoilless fraction for this source at $4.2^\circ$K is $f_s = 0.062$ (or 0.066 if one subtracts a background due to an unresolvable 80-keV gamma ray with 7% intensity). This corresponds to the characteristic temperature $\theta_M = 170^\circ$, which is quite close to the $180^\circ$ one would predict from the Debye temperature of aluminum and the concept of unchanged force constants.[2]

The Cs absorber contained 0.56 g/cm$^2$ of high-purity metal. The data summarized in Table IV were obtained in a run of

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*University of Western Australia.

[1] G. J. Perlow, A. J. F. Boyle, J. H. Marshall, and S. L. Ruby, Phys. Letters 17, 219 (1965).

[2] H. J. Lipkin, Ann. Phys. (N. Y.) 23, 28 (1963).

TABLE IV. Summary of results.

| | |
|---|---|
| Fractional effect observed | $1.86 \pm 0.26 \times 10^{-4}$ |
| Effect corrected for background | $4.1 \pm 0.6 \times 10^{-4}$ |
| Observed width | $0.75 \pm 0.18$ mm/sec |
| Observed shift | $-0.158 \pm 0.057$ mm/sec |
| Shift corrected for zero-point motion | $-0.164 \pm 0.057$ mm/sec |
| Recoilless fraction $f_{Cs}$ at $4.2^\circ K$ | $5.5 \times 10^{-5}$ |
| Calculated characteristic temperature $\theta_M$ | $49 \pm 1^\circ K$ |

three weeks duration at $4.2^\circ K$, during which about $3 \times 10^{10}$ counts were registered.

The characteristic temperature of cesium is observed to be $\theta_M = 49 \pm 1^\circ K$. This may be compared with the Debye temperature, which at $T = 0^\circ K$ has the value $\theta_D(0) = 40.5^\circ K$. The value of $\theta_D$ dips to $36^\circ$ at $T = 2^\circ K$ and then rises to $45^\circ$ at $T = 9^\circ K$. Our result that $\theta_M > \theta_D(0)$ may be shown to indicate that the normalized density-of-states function $N(\nu)$ drops initially below the Debye-model value $N_D(\nu)$ and hence goes to zero at a frequency greater than that corresponding to $\theta_D(0)$. This is consistent with the temperature dependence of the Debye temperature.

Because of the considerable difference in $\theta_M$ between source and absorber, there is an appreciable second-order Doppler shift from the difference in mean-square zero-point velocities. After correcting, cesium metal is observed to have a shift of $-0.16 \pm 0.06$ with respect to the alloy source. From other measurements, the species $Cs^+$ is known to be shifted to $-0.32 \pm 0.02$. Thus, quite remarkably, the cesium formed in the decay of the alloy acts as if it had twice as many 6s electrons as the atom in the metal.

One of the purposes of the experiment was to look for evidence for a spin-density wave structure, like that proposed to account for the optical properties of potassium. No such structure has been found. If the wave is static, a polarization less than 0.01 Bohr magneton per atom is required by the data.

## American Physical Society, Division of Plasma Physics

## Boston, 2—5 November 1966

### SLAB-MODEL THEORY OF ADMITTANCE OF HIGH-FREQUENCY PLASMOIDS

M. Hasan,* Albert J. Hatch, and J. Taillet†

A theory of the complex admittance $y_d = g_d + j\, b_d$ of resonant high-frequency discharges between parallel electrodes is presented. The theory is based on a one-dimensional model in which the plasmoid in the discharge region is assumed to consist of a central slab of free-electron plasma and two adjoining vacuum sheath regions which extend to the electrodes. By fitting the theory to measured values of admittance[1] as a function of the pressure parameter $\gamma = \nu_c/\omega$, we obtain values of $\theta^2$ (the ratio of total sheath length to electrode separation) and of $\alpha^2 = \omega_p^{\ 2}/\omega^2$ (plasma density normalized to cutoff density at rf radian frequency $\omega$). The measured values of admittance used in this fitting process are shown in Fig. 10 as a smoothed curve in the complex g-b plane. The fitted values of $\theta^2$ and $\alpha^2$ are shown in Fig. 11. The decrease of sheath length $\theta^2$ with increasing pressure $\gamma$ is in good agreement with visual observation. However, the increase of density $\alpha^2$ is somewhat larger than expected on the basis of probe measurements. Also shown in Fig. 11 is the square of the normalized characteristic geometric frequency $\alpha\theta$, a quantity that should have a value just slightly greater than 1. Why $\alpha\theta$ increases from 1.01 at $\gamma = 0.012$ (the lower threshold pressure for high-frequency plasmoids) to $\sim$1.40 at $\gamma = 0.195$

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*Permanent address: Northern Illinois University, DeKalb.

†Centre d'Etudes Nucléaires, Saclay.

[1] A. J. Hatch, R. J. Freiberg, and S. V. Paranjape, Bull. Am. Phys. Soc. 9, 333 (1964).

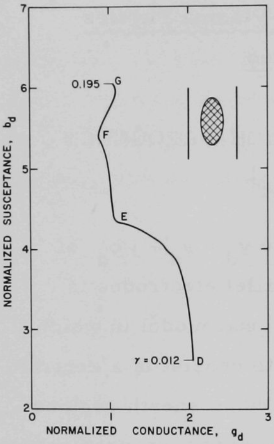


Fig. 10. Measured values of admittance of high-frequency plasmoids. The smoothed curve represents 32 values each of the admittance components $g_d$ and $b_d$ plotted as a function of pressure $\gamma$. The inset shows a cross section (shaded region) through a typical spheroidal plasmoid produced between plane parallel disk electrodes.

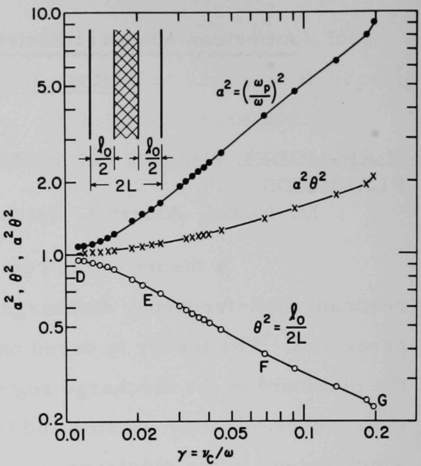


Fig. 11. Normalized sheath length $\theta^2$ and normalized plasma density $\alpha^2$ obtained by fitting the slab-model theory to the curve in Fig. 10. (The plotted points represent the fitted values and do not necessarily correspond to the original experimental values.) The plot of $\alpha^2\theta^2$ represents the square of the normalized characteristic geometric frequency. The inset diagram shows the one-dimensional slab model that is assumed to be equivalent to the plasmoid portrayed in Fig. 10.

(the upper limiting pressure for plasmoids) is not yet fully understood. However, this increase is believed to be due in part to $\nu_c$ increasing less rapidly with pressure than has been assumed. These results appear to support a plasma-slab description of plasmoids.

## APPARATUS FOR STUDYING PLASMA CONFINEMENT IN HIGH-FREQUENCY FIELDS

Albert J. Hatch

A facility for the study of plasmas in standing-wave fields in resonant cavities is described. The major components are a cylindrical cavity and a klystron amplifier tunable from 610 to 985 MHz and capable of delivering cw output power continuously adjustable from 0 to 2 kW. Ancillary components include an automatic impedance plotter and a 3-port circulator functioning as an isolator. An important capability of the uhf power system is that the frequency can be shifted and impedance-matching adjustments can be made (with coaxial tuning stubs) without interrupting the delivery of power to maintain the plasma. The cavity is excited in either the $TM_{010}$ or $TE_{011}$ dipole modes in

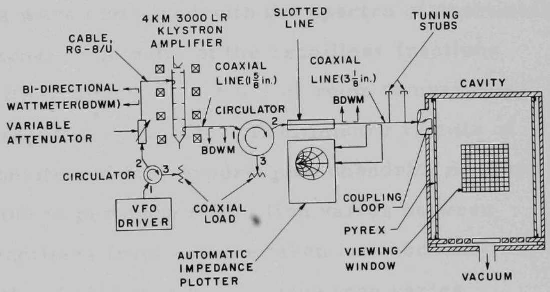


Fig. 12. Schematic block diagram of major components of plasma confinement apparatus. A low-power uhf signal (1—10 W) from the variable-frequency oscillator VFO (lower left) drives the klystron power amplifier which is a 4-cavity tube, tunable from 610 to 985 MHz, and capable of delivering up to 2 kW of cw output power. This power is transmitted via rigid coaxial line through a ferrite circulator which functions as an isolator to protect the klystron from the effects of possible severe mismatch in impedance due to plasma loading characteristics. The power then passes through a slotted line for precision measurements of electrical parameters of the cavity, an rf coupler to the automatic impedance plotter, a pair of tuning stubs, and then is fed to the cavity by a coupling loop. The cavity in the first version shown here was fabricated from copper and copper-clad stainless steel, all silver plated. It is 33 cm in diameter and 42 cm long, and has a Pyrex vacuum liner and 7 rf probe ports (not shown). Vacuum is provided by an ordinary oil diffusion pump system with a throttling valve for adjustment of pressure.

which confinement is not expected to occur (and which therefore act as control modes), or in the $TM_{011}$ or $TE_{012}$ quadrupole modes in which confinement is expected to occur. The facility has the theoretical capability of establishing steady-state potential wells for plasmas,[1,2] the depths being of the order of 70 eV. A block diagram of the essential components of this facility is shown in Fig. 12. A photograph of the facility appeared in an earlier report.[3]

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[1] A. J. Hatch, Phys. Rev. Letters 6, 53 (1961).

[2] A. J. Hatch and M. Hasan, Bull. Am. Phys. Soc. 11, 376 (1966).

[3] Argonne National Laboratory Report ANL-7246 (Annual Review 1965—1966), p. 117.

## Annual Meeting of the Meteoritical Society

## Smithsonian Institution, Washington, D.C., 3—5 November 1966

### MÖSSBAUER DETERMINATION OF THE RATIO OF OLIVINE IRON TO PYROXENE IRON IN THE HIGH-IRON AND LOW-IRON GROUPS OF STONE METEORITES

E. L. Sprenkel-Segel and G. J. Perlow

The Mössbauer effect in $Fe^{57}$ was used to measure the ratio of olivine iron to pyroxene iron in a series of eight stone meteorites. The method was similar to that described earlier[1] except for higher resolution. The source was $Co^{57}$ diffused into chromium metal. Each absorber consisted of about 20 $mg/cm^2$ of pulverized meteorite. A resonance absorption spectrum for each meteorite was obtained at liquid nitrogen temperature and at room temperature. The spectra were compared with the spectra of chemically analyzed olivine and pyroxene. The ratio of the recoilless fractions was found to be f(olivine)/f(pyroxene) = $1.2 \pm 0.1$ at room temperature and $1.1 \pm 0.1$ at liquid nitrogen temperature. Preliminary results of measurements on four bronzite and four hypersthene chondrite meteorites show that the ratio of olivine to pyroxene absorption varies between 1.7 and 2.5. When the recoilless fractions are taken into account, the result is that the ratio of the olivine iron to pyroxene iron varies between 1.5 and 2.2 for the eight samples.

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[1] E. L. Sprenkel-Segel and S. S. Hanna, Geochim. et Cosmochim. Acta 28, 1913 (1964).

# III. ABSTRACTS OF PAPERS ACCEPTED FOR PUBLICATION

## EQUILIBRIUM COMPOSITION OF SELENIUM VAPOR; THE THERMODYNAMICS OF THE VAPORIZATION OF HgSe, CdSe, AND SrSe

J. Berkowitz and W. A. Chupka

J. Chem. Phys. (1 December 1966)

The vapor compositions of SrSe, CdSe, HgSe, hexagonal selenium, α-monoclinic selenium, and some mixed sulfur-selenium crystals have been studied by mass spectrometric analysis. Dissociation energies of $Se_2$ (71.2 ± 2 kcal/mole) and SrSe (59.1 ± 3 kcal/mole) were obtained. The heats and free energies of formation of the various $Se_n$ molecular species detected in the vapor are also given. There is no significant difference between the vaporization behavior of the two Se allotropes. Mixed sulfur-selenium molecules form very slowly at room temperature, but they form more readily at higher temperature, and quenching to room temperature retains the mixed configurations.

## INTERFERENCE BETWEEN THE 16.62- AND 16.92-MEV LEVELS IN $^8Be$

C. P. Browne,* W. D. Callender,* and J. R. Erskine

Phys. Letters (15 November 1966)

The $^{10}B(d,\alpha)^8Be$ reaction reveals an asymmetry in the shapes of the alpha-particle groups corresponding to the 16.62- and 16.92-MeV states in $^8Be$. A simple two-level resonance formula which includes an interference term is found to fit the data.

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*University of Notre Dame, Indiana.

## THE (d,n) REACTION ON $Mg^{24}$ AND $Si^{28}$

S. G. Buccino,* D. S. Gemmell, L. L. Lee, Jr., J. P. Schiffer, and A. B. Smith*

Nucl. Phys. (October 1966)

The reactions $Mg^{24}(d,n)Al^{25}$ and $Si^{28}(d,n)P^{29}$ were studied. J-dependent effects similar to those observed in (d,p) reactions were seen. Pronounced differences in neutron distributions resulting from $\ell_p=2$ transitions to the 1.36-MeV ($\frac{3}{2}^+$) and the 1.96-MeV ($\frac{5}{2}^+$) states in $P^{29}$, and to the ground state ($\frac{5}{2}^+$) and 0.95-MeV state ($\frac{3}{2}^+$) in $Al^{25}$ were noted. These differences were observed at incident deuteron energies of 7.0, 9.0, and 10.0 MeV. Absolute differential cross sections were determined for transitions to the states at 0, 0.45, 0.95, 1.79, 2.48, 2.68, and 3.06 MeV in $Al^{25}$. Relative cross sections were determined for the states at 0, 1.36, 1.96, and 3.43 MeV in $P^{29}$. The data were analyzed by use of DWBA calculations, and spectroscopic factors were obtained for most of the above transitions. The results are compared with structure in the mirror nuclei $Mg^{25}$ and $Si^{29}$.

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*Reactor Physics Division.

## IMPROVED SOLUTION TO THE BETHE-FADDEEV EQUATIONS

Ben Day

Phys. Rev. (18 November 1966)

An approximate analytic solution is derived for the Bethe-Faddeev three-body equations in nuclear matter. The solution is no more complicated than the original approximation proposed by Bethe, but it is more accurate and avoids the discontinuities that appear in the original solution. In a certain limiting case, the solution agrees with the one previously proposed by Moszkowski on the basis of a variational treatment.

PRESYMMETRY

H. Ekstein

Phys. Rev. (25 January 1967)

Even in the presence of external fields, space-time symmetry implies nontrivial relations between observables at one time, i.e., kinematical relations. Symmetry operations at one time—translations, rotations, and (for Galilei symmetry) velocity shifts—can be performed on observation-producing and on state-producing instruments, regardless of the existence of an external field. Furthermore, it is possible to give an operational definition of every initial state intrinsically, i.e., regardless of the external field. The precise statement of this empirical fact explains, for example, why a particle in an external field has integral or half-integral eigenvalues of the spin, why a Hamiltonian exists even in the presence of a time-dependent external field, and why (for Galilei symmetry) the canonical commutation relations are still valid, although the full space-time symmetry from which these results can be derived has been destroyed. It is pointed out that the rigorous validity of kinematical relations in spite of strong breaking of the underlying space-time symmetry is analogous to the rigorous validity of equal-time current commutation rules in spite of the breaking of the underlying U(3) symmetry.

DECAY OF $Co^{55}$; LEVELS IN $Fe^{55}$

H. J. Fischbeck, F. T. Porter,* M. S. Freedman,* F. Wagner, Jr.,* and H. H. Bolotin

Phys. Rev. (21 October 1966)

The decay of 18-h $Co^{55} \rightarrow Fe^{55}$ has been re-examined with a magnetic beta spectrometer and a Ge(Li) detector. It has been established that both the 1316.4-keV and 411.4-keV levels are populated in the gamma cascades. Positron emission and electron capture populate the 1408.4-keV level (36%), the 1316.4-keV level (5%), and the 931.2-keV level (54%). The remaining 5% of the decay populates seven levels above 1408 keV. Positron decay to the 411-keV level and to the ground state in sum is $< 3 \times 10^{-5}$ per disintegration. From the endpoint of the maximum-energy positron group, $E_0 = (1513 \pm 2)$ keV, feeding the 931.2-keV gamma ground-state transition, the total decay energy is

*Chemistry Division.

found to be (3466 ± 2) keV. The decay scheme requires only levels already known in $Fe^{55}$ from nuclear reaction studies. A survey of the reaction data and the decay information reveals that the only conflict is the assignment of $\ell = 4$ (from some of the $Fe^{54}(d,p)Fe^{55}$ studies) to the level at 2589 keV.

## AN ON-LINE COMPUTER SYSTEM IN USE WITH LOW-ENERGY NUCLEAR PHYSICS EXPERIMENTS

D. S. Gemmell

Nucl. Instr. Methods (January 1967)

The computing system described is used on-line with experiments performed at the 4-MeV Van de Graaff and the tandem Van de Graaff accelerators at Argonne National Laboratory. The requirements for the system are listed and the hardware and software obtained to fulfill these requirements are described. Some typical applications of the system are given.

## INDUCTANCE-VARIATION METHOD OF MEASURING CHARACTERISTICS OF ELECTROMAGNETIC LEVITATION SYSTEMS

Albert J. Hatch and W. E. Smith*

J. Appl. Phys. (February 1967)

A recently developed general theory of electromagnetic levitation of conducting bodies is applied in a new method of examining the levitation and stability of levitating bodies of arbitrary shape in the fields of coil systems of arbitrary configuration. Introducing the conducting body into the magnetic field of the coils changes the apparent inductance of the coils by an amount $\Delta L$ which is readily measured directly. The pertinent result of the theory is that the levitational force is proportional to the gradient of $\Delta L$. The validity and feasibility of the method are demonstrated by measurements in several typical cases.

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*The University of New South Wales, Sydney, Australia.

## MISSING SU(3) MULTIPLETS AND $SU(6)_W$ SELECTION RULES

D. Horn,* H. J. Lipkin, and S. Meshkov*

Phys. Rev. Letters (5 December 1966)

We present W-spin selection rules which prohibit many resonances having high isospin and hypercharge from displaying dominant two-body decay modes, appearing as bumps in meson-baryon scattering cross sections, or being produced by simple peripheral meson exchange. Thus, present experimental evidence against the existence of these states is inconclusive, and a search for more complicated production mechanisms and decay modes is suggested.

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*High-Energy Physics Division.

## DENSITY OF STATES OF DEGENERATE FERMI SYSTEMS WITH PERIODIC LEVEL SCHEMES

Peter B. Kahn and Norbert Rosenzweig

Phys. Letters (15 August 1966)

An accurate and transparent asymptotic formula has been derived for the density of states of a degenerate Fermi system with an arbitrary periodic independent-particle energy level scheme. The work generalizes, unifies, and simplifies earlier treatments of related problems.

## QUARK MODELS, UNIVERSALITY, SYMMETRY, AND HIGH-ENERGY SCATTERING

C. A. Levinson,* N. S. Wall,* and H. J. Lipkin

Phys. Rev. Letters (21 November 1966)

New relations between meson-baryon and baryon-baryon cross sections are found by making use of predictions for scattering on deuteron targets. These are in better agreement with experiment than previously derived relations and provide a better parameterization for the quark-model amplitudes. They show that universal coupling of

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*University of Maryland.

$\omega$ and $\varphi$ Regge trajectories to mesons and baryons is a good approximation, but that the ratio of the two couplings is about 20% greater than predicted by SU(3) and SU(6).

## ANALYSIS OF INTERMEDIATE STRUCTURE IN TERMS OF LEVEL-PARAMETER STATISTICS

J. E. Monahan and A. J. Elwyn

Nucl. Phys.

Intermediate structure observed in the neutron total cross sections of Mo and Sn is discussed in terms of expected statistical fluctuations of the widths and spacings of compound-nucleus levels. Although the observed amplitude of this structure can be explained by such fluctuations, the data show correlations that are significantly inconsistent with this interpretation.

## ANALYSIS OF THE INTERMEDIATE STRUCTURE OBSERVED IN THE NEUTRON CROSS SECTION OF $^{19}F$

J. E. Monahan and A. J. Elwyn

Phys. Rev. (20 January 1967)

In measurements of the angular distribution and polarization of neutrons scattered from $^{19}F$ at neutron energies between 0.2 and 2.2 MeV, resonances are observed to have widths that are larger than the widths usually associated with states of the compound nucleus but are considerably smaller than the widths of single-particle resonances. A phase-shift analysis of these data is shown to be consistent with the interpretation of this intermediate structure in terms of doorway states.

ON THE SCALING OF x-RAY PHOTOGRAPHS

J. E. Monahan, M. Schiffer,* and J. P. Schiffer

Acta Cryst.

A simple general procedure is given for scaling x-ray photographs. The method avoids some of the approximations and difficulties of earlier procedures and should be more economical of computer time.

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*Biological and Medical Research Division.

THE $Ca^{46}(He^3,d)Sc^{47}$ REACTION

J. J. Schwartz,* W. Parker Alford,* and A. Marinov

Phys. Rev.

The level structure of $Sc^{47}$ has been studied by means of the $Ca^{46}(He^3,d)Sc^{47}$ reaction. Thirty-three levels have been observed up to an excitation of 7.5 MeV in $Sc^{47}$. Angular distributions were measured and compared with DWBA calculations to obtain values of the orbital-angular-momentum transfer and spectroscopic factors. All of the $f_{7/2}$ strength and part of the $p_{3/2}$ and $p_{1/2}$ strength are observed, but no more than 30% of the total $f_{5/2}$ strength is observed below an excitation of 7.5 MeV.

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*University of Rochester.

RADIATIVE CAPTURE BY $F^{19}$: THE GIANT DIPOLE RESONANCES IN $Ne^{20}$

R. E. Segel, Z. Vager, L. Meyer-Schützmeister, P. P. Singh, and R. G. Allas

Nucl. Phys.

The radiative capture of protons by $F^{19}$ has been studied over the range of proton bombarding energies from 2.88 MeV to 12.80 MeV. The most intense capture gamma rays are $\gamma_0$ to the ground state and $\gamma_1$ to the first excited state in $Ne^{20}$. The yield curves for both $\gamma_0$

and $\gamma_1$ are dominated by the E1 giant resonance with the $\gamma_1$ giant resonance displaced upward in excitation energy from the $\gamma_0$ giant resonance. Strong, well correlated structure is present in the yield curves; the structure has a characteristic width of about 175 keV. Extensive angular-distribution measurements showed that the angular distributions do not vary greatly with energy. The angular distributions are incompatible with $\gamma_0$ and $\gamma_1$ emanating from the same levels of the compound nucleus. The integrated yields, structure, and angular distributions are compared with the results of other $(p, \gamma)$ studies of the E1 giant resonance and some of the features of this and other radiative-capture experiments are discussed in terms of the shell model.

## FREQUENCY OF SPURIOUS "INTERMEDIATE RESONANCES" IN RANDOMLY GENERATED CROSS SECTIONS

P. P. Singh,* P. Hoffman-Pinther,* and D. W. Lang

Phys. Letters (24 October 1966)

A program to generate cross sections with parameters chosen in a random fashion from preset distributions showed the existence of spurious "intermediate structures." Calculations based on the model used and scanning of the cross section showed that in a sample of 25 $\Gamma_{cn}$ there is 30% chance of finding a resonance 6 $\Gamma_{cn}$ wide with $\sigma_{peak} = 1.4\ \sigma_{average}$. Widths alone, therefore, are not reliable signatures of the real intermediate structures.

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*Indiana University.

## GAMMA-RAY SPECTRUM FROM THERMAL-NEUTRON CAPTURE IN $Sm^{149}$, AND ASSOCIATED ENERGY LEVELS IN $Sm^{150}$

R. K. Smither

Phys. Rev. (21 October 1966)

The gamma-ray spectrum resulting from thermal-neutron capture in $Sm^{149}$ was investigated with the Argonne 7.7-m bent-crystal spectrometer. The observed spectrum consisted of 217 gamma rays with energies between 40 keV and 2.4 MeV. The bent-crystal gamma-ray data were combined with the conversion-electron data of Bieber et al.

and Groshev et al. to obtain K conversion coefficients for fifty of the observed gamma-ray transitions. These precision measurements of gamma-ray energies, intensities, and conversion coefficients were combined with a set of $\gamma$-$\gamma$ coincidence and $\gamma$-$\gamma$ angular-correlation measurements [with a similar source of $Sm^{149}(n,\gamma)Sm^{150}$ gamma rays] to develop a partial level scheme for $Sm^{150}$, in which the excitation energies (keV) and the spins and parities (in brackets) are: ground state [$0^+$], 333.94[$2^+$], 740.43[$0^+$], 773.33[$4^+$], 1046.13[$2^+$], 1071.39[$3^-$], 1165.57[$2^+$], 1193.83[$2^+$], 1278.78[$3^+$], 1357.55[$3^-$], 1449.11[$4^+$], 1504.48[$3^+$], and 1642.55[$4^+$]. In this partial level scheme, the spin and parity assignments for all 14 levels are uniquely defined. The energy levels at 1279.05, 1449.15, and 1504.42 keV are of particular interest because they exhibit strong E2 transitions to the $4^+$ state at 773.51 keV and suggest the presence of strong collective components in their wave functions. The previously published radioactive-decay, $(n,\gamma)$, and charged-particle work on $Sm^{150}$ were then combined with the crystal diffraction data to define twelve additional levels in $Sm^{150}$. This extended level scheme of $Sm^{150}$ agrees well with much of the previously published work and removes many of the previous uncertainties in the level scheme.

## USE OF CRYSTAL DIFFRACTION WITH A Ge-DIODE DETECTOR FOR HIGH-RESOLUTION GAMMA-RAY SPECTROSCOPY

R. K. Smither and A. I. Namenson

Rev. Sci. Instr. (January 1967)

The Argonne 7.7-m bent-crystal gamma-ray spectrometer is combined with a lithium-drifted Ge-diode detector to perform high-resolution gamma-ray spectroscopy on complicated neutron-capture gamma-ray spectra. The system combines the energy precision of the bent-crystal spectrometer with the high resolution of the Ge diode. The system is most useful in the 1—3-MeV energy range where both the precision and energy resolution obtained by the combined system frequently are from 3 to 10 times those of either the bent crystal or the Ge diode used individually. A 50-fold improvement in the signal-to-background ratio is obtained through the use of the combined system. The use of the system is illustrated by $Cd^{113}(n,\gamma)Cd^{114}$ spectra. The Argonne system is compared with other possible crystal diffraction arrangements and with coincidence and anticoincidence techniques for improving the quality of the $(n,\gamma)$ measurements. The application of the Argonne system to the comparison of $(n,\gamma)$ transitions with gamma transitions following radioactive decay is discussed. New values for the strong gamma transition associated with the decay of $Cs^{137}$ and $Co^{60}$ are quoted along with a more precise value (1294.35 ± 0.30 keV) for the gamma ray associated with the decay of $A^{41}$. Improvements in the Argonne system are described and a proposed extension of the system for precision energy measurements in the 2—5 MeV range is discussed.

## ANGULAR DISTRIBUTIONS FOR INELASTIC DEUTERON SCATTERING FROM SAMARIUM

B. Zeidman, B. Elbek,* B. Herskind,* and M. C. Olesen*

Nucl. Phys. (October 1966)

The elastic and inelastic scattering of 12-MeV deuterons from targets of $^{148}Sm$, $^{150}Sm$, $^{152}Sm$, and $^{154}Sm$ has been investigated. Angular distributions for the elastic group and for the more prominent inelastic groups were measured by means of solid-state counters. Supplementary information was obtained from high-resolution magnetic-spectrograph data. The elastic angular distributions are smooth and without diffraction structure. The absolute cross section at back angles decreases with increasing mass number. This effect can probably be ascribed to differences in the inelastic excitations since the distributions for the sum of elastic and inelastic intensity are almost identical for all the nuclei. The shape of the angular distributions for the collective $2^+$, $4^+$, and (when observed) for the $6^+$ levels, for each angular momentum is very similar in all the nuclei, although the character of the levels changes from vibrational to pure rotational. The same is true for the distributions of the strongly excited $3^-$ levels. It is thus indicated that the angular distributions give a simple determination of the multipolarity of the excitation, the tendency being a decrease in forward/backward ratio with increasing multipolarity.

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# IV. PUBLICATIONS SINCE THE LAST REPORT

## PAPERS AND BOOKS

PHOTOIONIZATION OF HIGH-TEMPERATURE VAPORS. I. THE IODIDES OF SODIUM, MAGNESIUM, AND THALLIUM
J. Berkowitz and W. A. Chupka
J. Chem. Phys. 45, 1287-1298 (15 August 1966)

DEBYE-WALLER FACTOR FOR THE CESIUM ION IN THE CESIUM HALIDES BY MEASUREMENT OF THE MÖSSBAUER EFFECT IN $Cs^{133}$
A. J. F. Boyle and G. J. Perlow
Phys. Rev. 151, 211-214 (4 November 1966)

OBSERVATIONS OF THE MÖSSBAUER EFFECT IN $Cs^{133}$
A. J. F. Boyle and G. J. Perlow
Phys. Rev. 149, 165-170 (9 September 1966)

INTERFERENCE BETWEEN THE 16.62- AND 16.92-MEV LEVELS IN $^{8}Be$
C. P. Browne,* W. D. Callender,* and J. R. Erskine
Phys. Letters 23, 371-373 (7 November 1966)

THE (d,n) REACTION ON $Mg^{24}$ AND $Si^{28}$
S. G. Buccino (Reactor Physics), D. S. Gemmell, L. L. Lee, Jr., J. P. Schiffer, and A. B. Smith (Reactor Physics)
Nucl. Phys. 86, 353-362 (October 1966)

INTERNAL SYMMETRIES IN A COUPLED-CHANNEL SOLUBLE MODEL WITH INELASTICITY
James T. Cushing
Phys. Rev. 148, 1558-1573 (26 August 1966)

IMPROVED SOLUTION TO THE BETHE-FADDEEV EQUATIONS
Ben Day
Phys. Rev. 151, 826-829 (18 November 1966)

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*University of Notre Dame, Indiana.

INTRODUCTION TO NUCLEAR MATTER
Benjamin D. Day
Argonne National Laboratory Reviews 3(3), 75-79 (July 1966)

ENERGY LEVEL STRUCTURE OF $Ca^{40}$ AS OBSERVED WITH THE $K^{39}(He^3,d)Ca^{40}$ REACTION
John R. Erskine
Phys. Rev. 149, 854-862 (23 September 1966)

DECAY OF $Co^{55}$; LEVELS IN $Fe^{55}$
H. J. Fischbeck, F. T. Porter (Chemistry), M. S. Freedman (Chemistry), F. Wagner, Jr. (Chemistry), and H. H. Bolotin
Phys. Rev. 150, 941-955 (21 October 1966)

MISSING SU(3) MULTIPLETS AND $SU(6)_W$ SELECTION RULES
D. Horn (High-Energy Physics), H. J. Lipkin, and S. Meshkov (High-Energy Physics)
Phys. Rev. Letters 17, 1200-1203 (5 December 1966)

PROPERTIES OF PARTIAL RADIATION WIDTHS IN $^{196}Pt$
H. E. Jackson, J. Julien,* C. Samour,* A. Bloch,* C. Lopata,* J. Morgenstern,* H. Mann (Electronics), and G. E. Thomas
Phys. Rev. Letters 17, 656-658 (19 September 1966)

DENSITY OF STATES OF DEGENERATE FERMI SYSTEMS WITH PERIODIC LEVEL SCHEMES
Peter B. Kahn and Norbert Rosenzweig
Phys. Letters 22, 307-309 (15 August 1966)

MEAN RESIDENCE TIMES OF ALKALI IONS ON POLYCRYSTALLINE WOLFRAM SURFACES AS STUDIED WITH A PULSED-MOLECULAR-BEAM MASS SPECTROMETER
Manfred Kaminsky
Ann. Physik 18, 53-70 (August 1966)

PROFESSOR DR. ERICH HÜCKEL ZUM SIEBZIGSTEN GEBURTSTAGE AM 9. AUGUST 1966
Manfred Kaminsky
Ann. Physik 18, 3-5 (August 1966)

MEASUREMENT OF THE ELECTRON-NEUTRON INTERACTION BY THE ASYMMETRICAL SCATTERING OF THERMAL NEUTRONS BY NOBLE GASES
V. E. Krohn and G. R. Ringo
Phys. Rev. 148, 1303-1311 (26 August 1966)

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*Centre d'Etudes Nucléaires de Saclay.

THE REACTION MATRIX AND EFFECTIVE SHELL-MODEL INTERACTIONS FOR THE Ni ISOTOPES
R. D. Lawson, M. H. Macfarlane, and T. T. S. Kuo*
Phys. Letters 22, 168-172 (1 August 1966)

QUARK MODELS, UNIVERSALITY, SYMMETRY, AND HIGH-ENERGY SCATTERING
C. A. Levinson,† N. S. Wall,† and H. J. Lipkin
Phys. Rev. Letters 17, 1122-1125 (21 November 1966)

ANOMALY IN THE ENERGY DEPENDENCE OF THE ANGULAR DISTRIBUTIONS FOR DEUTERONS SCATTERED FROM $Mg^{24}$ IN THE ENERGY RANGE FROM 6 TO 13 MEV
C. Mayer-Böricke and R. H. Siemssen
Z. Naturforsch. 21a, 958-963 (July 1966)

NEUTRON CROSS SECTIONS OF THE BORON ISOTOPES FOR ENERGIES BETWEEN 10 AND 500 KEV
F. P. Mooring, J. E. Monahan, and C. M. Huddleston
Nucl. Phys. 82, 16-32 (July 1966)

AN ALPHA-DEUTERON-LAMBDA MODEL OF THE HYPERNUCLEUS ${}^{7}_{\Lambda}Li$
J. W. Murphy‡ and A. R. Bodmer
Nucl. Phys. 83, 673-689 (1966)

MÖSSBAUER EFFECT IN COMPOUNDS OF $^{127}I$
G. J. Perlow and M. R. Perlow
J. Chem. Phys. 45, 2193-2200 (15 September 1966)

CRYSTAL STRUCTURES OF V-Fe ALLOYS AS DETERMINED BY THE MÖSSBAUER EFFECT IN $Fe^{57}$
R. S. Preston, D. J. Lam (Metallurgy), M. V. Nevitt (Metallurgy), D. O. Van Ostenburg (Metallurgy), and C. W. Kimball (Solid-State Science)
Phys. Rev. 149, 440-449 (16 September 1966)

FREQUENCY OF SPURIOUS "INTERMEDIATE RESONANCES" IN RANDOMLY GENERATED CROSS SECTIONS
P. P. Singh,| P. Hoffman-Pinther,| and D. W. Lang
Phys. Letters 23, 255-257 (24 October 1966)

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†University of Maryland.

‡The University, Manchester, England.

|Indiana University.

GAMMA-RAY SPECTRUM FROM THERMAL-NEUTRON CAPTURE IN $Sm^{149}$, AND ASSOCIATED ENERGY LEVELS IN $Sm^{150}$

R. K. Smither

Phys. Rev. 150, 964-984 (21 October 1966)

ANALYSIS OF γ-γ CASCADES BY POLARIZATION AND DIRECTIONAL CORRELATION: DECAY OF $Rh^{101g}$

G. T. Wood, S. Koički,* and A. Koički*

Phys. Rev. 150, 956-963 (21 October 1966)

LOWEST $T=\frac{3}{2}$ STATE IN $P^{29}$

D. H. Youngblood, G. C. Morrison, and R. E. Segel

Phys. Letters 22, 625-626 (15 September 1966)

ANGULAR DISTRIBUTIONS FOR INELASTIC DEUTERON SCATTERING FROM SAMARIUM

B. Zeidman, B. Elbek,† B. Herskind,† and M. C. Olesen†

Nucl. Phys. 86, 471-480 (October 1966)

## REPORTS AT MEETINGS

Nuclear Structure Study with Neutrons (Proceedings of the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, 19-23 July 1965), edited by M. Nève de Mévergnies, P. Van Assche, and J. Vervier (North-Holland Publishing Co., Amsterdam, 1966)

PROTON STRENGTH FUNCTION MEASUREMENTS

A. J. Elwyn, A. Marinov, and J. P. Schiffer

p. 496

NEUTRON SCATTERING FROM NUCLEI NEAR A = 20

A. J. Elwyn, J. E. Monahan, R. O. Lane, F. P. Mooring, and A. Langsdorf, Jr.

p. 288—and repeated on pp. 537-538

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†Institute for Theoretical Physics, Copenhagen.

Nuclear Structure Study with Neutrons (Proceedings of the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, 19-23 July 1965), edited by M. Nève de Mévergnies, P. Van Assche, and J. Vervier (North-Holland Publishing Co., Amsterdam, 1966) (cont'd.)

MEASUREMENT OF RADIATION WIDTHS OF LOW-ENERGY NUCLEAR STATES BY RESONANCE SCATTERING OF THERMAL-NEUTRON-CAPTURE GAMMA RAYS
H. S. Hans, G. E. Thomas, and L. M. Bollinger
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PRECISION MEASUREMENTS ON HIGH-ENERGY GAMMA RAYS FROM CAPTURE OF THERMAL NEUTRONS IN $Hf^{177}$, $Hf^{178}$, AND $Hf^{179}$
H. E. Jackson, A. Namenson, and R. K. Smither
p. 515

SMALL-ANGLE SCATTERING OF NEUTRONS
J. E. Monahan, A. J. Elwyn, R. O. Lane, A. Langsdorf, Jr., and F. P. Mooring
pp. 558-559

NEUTRON CROSS SECTIONS OF THE BORON ISOTOPES
J. E. Monahan and F. P. Mooring
pp. 530-531

THE DENSITY OF STATES OF A FERMI SYSTEM
N. Rosenzweig
pp. 309-310 + discussion on pp. 310-311

CAPTURE GAMMA-RAY SPECTRUM OF $Cd^{113}(n,\gamma)Cd^{114}$ AND THE ASSOCIATED ENERGY LEVELS IN $Cd^{114}$
R. K. Smither
p. 519

THE COMBINATION OF A BENT-CRYSTAL DIFFRACTION SPECTROMETER AND A Ge-DIODE DETECTOR FOR HIGH-RESOLUTION GAMMA-RAY SPECTROSCOPY
R. K. Smither and A. Namenson
pp. 519-520

p-WAVE RESONANCES IN $U^{238}$ AT VERY LOW ENERGY
G. E. Thomas and L. M. Bollinger
p. 534

Proceedings of the 2nd International Symposium on Polarization Phenomena of Nucleons, Karlsruhe, 6-10 September 1965, edited by P. Huber and H. Schopper (Birkhäuser Verlag, Basel and Stuttgart, 1966)

POLARIZATION IN THE SMALL-ANGLE SCATTERING OF 0.83-MEV NEUTRONS BY U
R. O. Lane, A. J. Elwyn, J. E. Monahan, A. Langsdorf, Jr., and F. P. Mooring
pp. 468-469

THE POLARIZED ION SOURCE FOR THE ARGONNE TANDEM
D. von Ehrenstein and D. C. Hess
pp. 88-90

Nuclear Spin-Parity Assignments (Proceedings of the Conference on Bases for Nuclear Spin-Parity Assignments, Gatlinburg, Tennessee, 11-13 November 1965), edited by N. B. Gove and R. L. Robinson (Academic Press, Inc., New York, 1966)

THE NUCLEAR SHELL MODEL—COMPARISON OF CALCULATIONS AND EXPERIMENTS
Malcolm H. Macfarlane
pp. 411-428

J DEPENDENCE OF ANGULAR DISTRIBUTIONS
J. P. Schiffer
pp. 384-405

ANALYSIS OF DOUBLY MIXED $\gamma$-$\gamma$ CASCADES BY USE OF POLARIZATION-DIRECTION AND DIRECTIONAL CORRELATIONS: DECAY OF 5-y $Rh^{101}$
G. T. Wood, S. Koički,* and A. Koički*
pp. 198-200

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*University of Pennsylvania.

Proceedings of the Williamsburg Conference on Intermediate Energy Physics, February 10-12, 1966, edited by H. O. Funsten (The College of William and Mary, Williamsburg, Virginia, 1966)

Unified presentation of two papers:

X RAYS FROM MUONIC ATOMS WITH SPHERICAL OR NEARLY SPHERICAL NUCLEI
R. E. Coté, W. V. Prestwich, S. Raboy, C. C. Trail, R. A. Carrigan, Jr.,* A. Gaigalas,* and R. B. Sutton*

and

STUDIES OF MUONIC ATOMS OF NON-SPHERICAL NUCLEI
R. B. Sutton,* A. Gaigalas,* R. A. Carrigan, Jr.,* R. E. Coté, W. V. Prestwich, S. Raboy, and C. C. Trail
Vol. I, pp. 51-75

Conference on Neutron Cross Section Technology, Washington, D.C., March 22-24, 1966, edited by P. B. Hemmig (Report No. CONF-660303, Clearing House for Federal Scientific and Technical Information, National Bureau of Standards, U.S. Department of Commerce, Springfield, Virginia)

NEW APPROACH TO NEUTRON RESONANCE SPECTROSCOPY
L. M. Bollinger
Book 2, pp. 1064-1072

Second Symposium on the Structure of Low-Medium Mass Nuclei, 21-23 April 1966, The Aerospace Research Laboratories, Wright-Patterson Air Force Base, Dayton, Ohio, edited by Paul Goldhammer and L. W. Seagondollar (Aerospace Research Laboratories, Dayton, Ohio, University of Kansas, Lawrence, Kansas, and North Carolina State University, Raleigh, North Carolina, 1966)

SHELL MODEL STUDIES IN NUCLEAR STRUCTURE
R. D. Lawson
pp. 6-37

THE GIANT DIPOLE RESONANCE IN LIGHT NUCLEI
L. Meyer-Schützmeister
pp. 195-222

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*Carnegie Institute of Technology.

Recent Progress in Nuclear Physics with Tandems, Heidelberg, Germany, 18-21 July 1966, edited by W. Hering (Max Planck Institute for Nuclear Physics, Heidelberg, 1966)

J DEPENDENCE IN DIRECT REACTIONS
John P. Schiffer
Session V b, pp. 1-18

Proceedings of the National Electronics Conference, Chicago, 3-5 October 1966, Vol. XXII (National Electronics Conference, Inc., Chicago, 1966)

CONTAINMENT OF PLASMAS IN RESONANT-CAVITY FIELDS
Albert J. Hatch and M. Hasan
pp. 962-966

## STUDENT REPORTS

A SIX-GAP SPECTROMETER IN THE STUDY OF THE DECAY OF $Xe^{125}$
David R. Parks
ACM student report to Grinnell College (23 December 1966)

THE KINETIC ENERGY DISTRIBUTION OF CHARGED FRAGMENTS PRODUCED IN COLLISIONS OF MOLECULAR IONS WITH NEUTRAL GASES
Roland L. Penny
CSUI-ANL student report to Rollins College (December 1966)

# V. PERSONNEL CHANGES IN THE ANL PHYSICS DIVISION

## NEW MEMBERS OF THE DIVISION

### Research Associate

Dr. Charles E. Johnson, A. E. R. E. Harwell, England. Mössbauer effect. Returned to Argonne on 24 October 1966 for a period of two months. He returned to Harwell on 15 December 1966.

### Post-Doctorals

Dr. Robert C. Bearse. Study of the E1 giant resonance. Came to Argonne on 1 September 1966.

Dr. Duane J. Buss, Notre Dame University. Neutron capture gamma-ray studies. Came to Argonne on 27 October 1966.

Dr. L. E. Campbell, Carnegie Institute of Technology. A variety of Mössbauer effect studies. Came to Argonne on 5 October 1966.

Dr. Alpo J. Kallio, University of Minnesota. Nuclear shell structure, effective interactions of nucleons in nuclei, and nuclear matter. Came to Argonne on 2 September 1966.

Dr. Franca T. Kuchnir, University of Illinois. Measurements on polarization and differential cross sections in the small-angle scattering of neutrons. Came to Argonne on 3 October 1966.

Dr. Hajime Ohnuma, The University of Tokyo. Experimental nuclear physics. Came to Argonne on 16 September 1966.

Dr. N. G. Puttaswamy, Stanford University. Study of radiative capture reactions induced by charged particles. Came to Argonne on 1 November 1966.

Dr. Peter Williams, King's College, London. Impact phenomena of ions and atoms on metal surfaces. Came to Argonne on 24 October 1966.

## University Users of the ANL Tandem

Mr. Delbert W. Devins, Indiana University. Short nuclear lifetimes with Doppler-shift techniques. First came to use the machine on 18 November 1966.

Mr. James W. Smith, Indiana University. Short nuclear lifetimes with Doppler-shift techniques. First came to use the machine on 24 October 1966.

## Co-op Technicians

Mr. Craig C. Biddle, University of South Florida, Tampa. Working with M. Kaminsky on the proton-stopping power of metal monocrystals. Came to ANL on 28 December 1966.

Mr. Glen W. Johnson, Antioch College, Yellow Springs, Ohio. Working with M. Kaminsky on secondary electron emission. Came to ANL on 19 September 1966.

## CSUI-ANL Honor Students

Mr. James F. Dill, John Carroll University, Cleveland, Ohio. Working with L. S. Goodman on the design of a sublimation pump and other components of the new atomic-beam machine. Came to ANL on 6 September 1966.

Mr. Richard J. Harris, Miami University, Oxford, Ohio. Working with F. P. Mooring on accelerator and beam-line techniques. Came to ANL on 6 September 1966.

Mr. David W. Knoble, Wheeling College, West Virginia. Working with G. T. Wood on gamma-gamma angular correlation. Came to ANL on 5 September 1966.

Miss Mary Ann C. Pajcic, Notre Dame College, Cleveland, Ohio. Working with J. R. Erskine on the study of nuclear states through the measurement of charged particles with a magnetic spectrograph. Came to ANL on 6 September 1966.

Mr. Roland L. Penny, Rollins College, Winter Park, Florida. Working with W. A. Chupka on measurement of the kinetic energy distribution of charged fragments produced in collisions of molecular ions with neutral gases. Came to ANL on 5 September 1966.

## Technicians

Mr. Vernon F. Blair, Jr., joined the Physics Division on 31 October 1966 to work with A. J. Elwyn.

Mr. Floyd H. Munson, Jr., joined the Physics Division on 20 December 1966 to work with J. R. Wallace.

## Secretary

Miss Jean Shaver joined the Physics Division on 6 September 1966 as secretary in B wing.

## PROMOTIONS

Mr. Charles H. Batson was promoted to Scientific Assistant on 1 December 1966.

Mr. John Bicek was promoted to Scientific Assistant on 1 December 1966.

Mr. Milton D. Machálek was promoted to Scientific Assistant on 1 December 1966.

Mr. Eugene Schultz was promoted to Chief Technician on 21 November 1966.

## LEAVES OF ABSENCE

Dr. Thomas H. Braid left ANL on 1 September 1966 for a year of study and research at A. E. R. E., Harwell, England. Single-neutron pickup from nuclei in the region $20 \leqslant Z \leqslant 50$ with 30-MeV protons; $\gamma$ rays in coincidence with the charged particles emitted in reactions. He expects to return to Argonne on 31 August 1967.

Dr. James E. Monahan left ANL on 1 September 1966 for a year of study and research at The Weizmann Institute of Science, Israel. Theory of nuclear reactions and scattering—especially the extension of shell-model calculations to the continuum. He expects to return to Argonne on 31 August 1967.

## PART-TIME APPOINTMENTS

Dr. Fritz Coester started teaching part time at the State University of Iowa on 1 October 1966.

Miss Jeanne P. Marion started teaching part time at the Chicago City College, Bogan Campus on 1 October 1966.

Dr. Ralph E. Segel has accepted a joint appointment with Northwestern University, starting on 15 September 1966.

## DEPARTURES

Dr. A. E. Blaugrund, research associate from The Weizmann Institute of Science, Rehovoth, Israel has been at Argonne since 31 August 1965. He has worked on Doppler-shift lifetime measurements, properties of the 13-keV transition in $Sc^{45}$, and decay schemes of Cu isotopes by $Ni(\alpha, p)$ reactions. He terminated at ANL on 7 October 1966 to return to The Weizmann Institute.

Dr. James T. Cushing, research associate from Imperial College, England, has been at Argonne since 7 September 1965. He has worked on internal symmetries in exactly soluble models. He terminated at ANL on 16 September 1966 to go to the University of Notre Dame, South Bend, Indiana.

Dr. Cecil F. Dam, research associate and ACM-ANL supervisor from Cornell College has been at Argonne since 7 June 1965. He has worked on magnetic perturbation of $\gamma$-$\gamma$ angular correlations. He terminated at ANL on 16 September 1966 to return to Cornell College, Mount Vernon, Iowa.

Dr. Dietrich Dehnhard, post-doctoral from Universität Marburg, Germany has been at Argonne since 1 April 1964. He has worked on charged-particle reactions. He terminated at ANL on 19 September 1966 to go to the School of Physics, University of Minnesota, Minneapolis, Minnesota.

Mr. Edward Kowalski, scientific assistant, has been at Argonne since 12 July 1957. He terminated at ANL on 23 September 1966.

Mr. Richard J. Mirdas, scientific technician, has been at Argonne since 12 April 1961. He terminated at ANL on 4 November 1966.

Dr. John M. Soper, research associate from A. E. R. E., Harwell has been at Argonne since 8 February 1965. He has collaborated with R. D. Lawson on concealed configuration mixing and the properties of the pseudonium isotopes and the neutron-proton interaction in nuclei. He terminated at ANL on 19 September 1966 to return to Harwell.

Dr. Dietrich Dehnhard, post-doctoral from University [illegible], Germany, has been at Argonne since 1 April [illegible] on charged-particle reactions. [illegible] on [illegible] September 1961 to go to the [illegible] University of Minnesota, Minneapolis, Minnesota.

Mr. Edward Kowalski, scientific assistant, has been at Argonne since 12 July 1957. He terminated at ANL on [illegible] 1961.

Mr. Richard [illegible] Mordas, scientific [illegible], has been at [illegible] since 12 April [illegible]. He terminated at ANL on [illegible] 1961.

Dr. John M. Soper, research associate from R. [illegible], has been at Argonne since 9 February 1961. [illegible] collaboration with Dr. D. Lawson on [illegible] mixing and the properties of the pseudo[illegible] and the [illegible] in nuclear [illegible] at ANL on [illegible] 1961 to return to [illegible].